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Modified dispersion law for spin waves coupled to a superconductor

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Abstract

© 2018 Author(s). In this work, we consider dispersion laws of spin waves that propagate in a ferromagnet/superconductor bilayer, specifically in a ferromagnetic film coupled inductively to a superconductor. The coupling is viewed as an interaction of a spin wave in a ferromagnetic film with its mirrored image generated by the superconductor. We show that, in general, the coupling enhances substantially the phase velocity of magnons in in-plane spin wave geometries. In addition, a heavy nonreciprocity of the dispersion law is observed in the magnetostatic surface spin wave geometry where the phase velocity depends on the direction of the wave propagation.

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References

[1] F. Bloch, Z. Phys. 61, 206 (1930). 10.1007/BF01339661
[2] R. W. Damon and J. R. Eshbach, J. Appl. Phys. 31, S104 (1960). 10.1063/1.1984622
[3] D. Stancil, Theory of Magnetostatic Waves (Springer-Verlag, New York, 1993).
[4] G. Csaba, A. Papp, and W. Porod, Phys. Lett. A 381, 1471 (2017). 10.1016/j.physleta.2017.02.042
[5] Y. Kajiwara, K. Harii, S. Takahashi, J. Ohe, K. Uchida, M. Mizuguchi, H. Umezawa, H. Kawai, K. Ando, K. Takanashi, S. Maekawa, and E. Saitoh, Nature 464, 262 (2010). 10.1038/nature08876
[6] A. V. Chumak, V. I. Vasyuchka, A. A. Serga, and B. Hillebrands, Nat. Phys. 11, 453 (2015). 10.1038/nphys3347
[7] A. Haldar, C. Tian, and A. O. Adeyeye, Sci. Adv. 3, 1700638 (2017). 10.1126/sciadv.1700638
[8] A. Khitun, R. Ostroumov, and K. L. Wang, Phys. Rev. A 64, 062304 (2001). 10.1103/PhysRevA.64.062304
[9] P. Andrich, C. F. de las Casas, X. Liu, H. L. Bretscher, J. R. Berman, F. J. Heremans, P. F. Nealey, and D. D. Awschalom, npj Quantum Inf. 3, 28 (2017). 10.1038/s41534-017-0029-z
[10] A. V. Chumak, A. A. Serga, and B. Hillebrands, Nat. Commun. 5, 4700 (2014). 10.1038/ncomms5700
[11] N. Sato, K. Sekiguchi, and Y. Nozaki, Appl. Phys. Express 6, 063001 (2013). 10.7567/APEX.6.063001
[12] M. Jamali, J. H. Kwon, S.-M. Seo, K.-J. Lee, and H. Yang, Sci. Rep. 3, 3160 (2013). 10.1038/srep03160
[13] A. A. Serga, A. V. Chumak, and B. Hillebrands, J. Phys. D Appl. Phys. 43, 264002 (2010). 10.1088/0022-3727/43/26/264002
[14] P. Gruszecki and M. Krawczyk, “Magnonic crystals,” in Wiley Encyclopedia of Electrical and Electronics Engineering (John Wiley & Sons, Ltd., 2016).
[15] I. A. Golovchanskiy, N. N. Abramov, V. S. Stolyarov, V. V. Bolginov, V. V. Ryazanov, A. A. Golubov, and A. V. Ustinov, Adv. Funct. Mater. 28, 1802375 (2018). 10.1002/adfm.201802375
[16] M. Donahue and D. Porter, OOMMF User’s Guide, Version 1.0, Interagency Report NISTIR 6376, National Institute of Standards and Technology, Gaithersburg, MD, 1999.
[17] J. E. Miltat and M. J. Donahue, “Numerical micromagnetics: Finite difference methods,” in Handbook of Magnetism and Advanced Magnetic Materials (John Wiley & Sons, Ltd., 2007).

[18] P. Deorani, J. H. Kwon, and H. Yang, Curr. Appl. Phys. 14, S129 (2014). 10.1016/j.cap.2013.11.008

[19] P. Wessels, A. Vogel, J.-N. Todt, M. Wieland, G. Meier, and M. Drescher, Sci. Rep. 6, 22117 (2016). 10.1038/srep22117

[20] T. Bracher, P. Pirro, J. Westermann, T. Sebastian, B. Lagel, B. V. de Wiele, A. Vansteenkiste, and B. Hillebrands, Appl. Phys. Lett. 102, 132411 (2013). 10.1063/1.4800005

[21] V. Vlaminck and M. Bailleul, Phys. Rev. B 81, 014425 (2010). 10.1103/PhysRevB.81.014425

[22] C. Liu, J. Chen, T. Liu, F. Heimbach, H. Yu, Y. Xiao, J. Hu, M. Liu, H. Chang, T. Stueckler, S. Tu, Y. Zhang, Y. Zhang, P. Gao, Z. Liao, D. Yu, K. Xia, N. Lei, W. Zhao, and M. Wu, Nat. Commun. 9, 738 (2018). 10.1038/s41467-018-03199-8

[23] A. Navabi, C. Chen, M. Aldosary, J. Li, K. Wong, Q. Hu, J. Shi, G. P. Carman, A. E. Sepulveda, P. K. Amiri, and K. L. Wang, Phys. Rev. Appl. 7, 034027 (2017). 10.1103/PhysRevApplied.7.034027

[24] Y. V. Khivintsev, L. Reisman, J. Lovejoy, R. Adam, C. M. Schneider, R. E. Camley, and Z. J. Celinski, J. Appl. Phys. 108, 023907 (2010). 10.1063/1.3435318

[25] B. V. de Wiele, S. J. Hamalainen, P. Balaz, F. Montoncello, and S. van Dijken, Sci. Rep. 6, 21330 (2016). 10.1038/srep21330

[26] G. Venkat, D. Kumar, M. Franchin, O. Dmytriiev, M. Mruczkiewicz, H. Fangohr, A. Barman, M. Krawczyk, and A. Prabhakar, IEEE Trans. Magn. 49, 524 (2013). 10.1109/TMAG.2012.2206820

[27] F. S. Ma, H. S. Lim, Z. K. Wang, S. N. Piramanayagam, S. C. Ng, and M. H. Kuok, Appl. Phys. Lett. 98, 153107 (2011). 10.1063/1.3579531

[28] I. A. Golovchanskiy, V. V. Bolginov, N. N. Abramov, V. S. Stolyarov, A. B. Hamida, V. I. Chichkov, D. Roditchev, and V. V. Ryazanov, J. Appl. Phys. 120, 163902 (2016). 10.1063/1.4965991

[29] M. Mruczkiewicz and M. Krawczyk, J. Appl. Phys. 115, 113909 (2014). 10.1063/1.4868905

[30] S. R. Seshadr, Proc. IEEE 58, 506 (1970). 10.1109/PROC.1970.7680

[31] T. Yukawa, J. Yamada, K. Abe, and J. Ikenoue, Jpn. J. Appl. Phys. 16, 2187 (1977). 10.1143/JJAP.16.2187

[32] I. A. Golovchanskiy, N. N. Abramov, V. S. Stolyarov, I. V. Shchetinin, P. S. Dzhumaev, A. S. Averkin, S. N. Kozlov, A. A. Golubov, V. V. Ryazanov, and A. V. Ustinov, J. Appl. Phys. 123, 173904 (2018). 10.1063/1.5025028

[33] J. Lindner, K. Lenz, E. Kosubek, K. Baberschke, D. Spoddig, R. Meckenstock, J. Pelzl, Z. Frait, and D. L. Mills, Phys. Rev. B 68, 060102 (2003). 10.1103/PhysRevB.68.060102